



## Activity 6

# The Electromagnetic Spectrum and Your Community



### Goals

In this activity you will:

- Explain electromagnetic radiation and the electromagnetic spectrum in terms of wavelength, speed, and energy.
- Investigate the different instruments astronomers use to detect different wavelengths in the electromagnetic spectrum.
- Understand that the atoms of each of the chemical elements have a unique spectral fingerprint.
- Explain how electromagnetic radiation reveals the temperature and chemical makeup of objects like stars.
- Understand that some forms of electromagnetic radiation are essential and beneficial to us on Earth, and others are harmful.

### Think about It

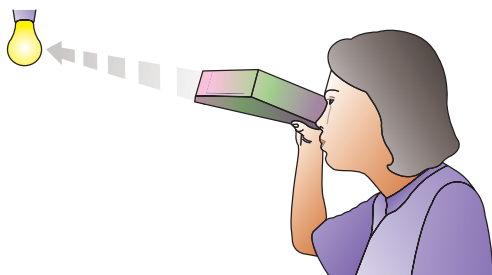
Look at the spectrum as your teacher displays it on the overhead projector. Record in your *EarthComm* notebook the colors in the order in which they appear. Draw a picture to accompany your notes.

- What does a prism reveal about visible light?
- The Sun produces light energy that allows you to see. What other kinds of energy come from the Sun? Can you see them? Why or why not?

What do you think? Record your ideas in your *EarthComm* notebook. Be prepared to discuss your responses with your small group and the class.

## Investigate

### Part A: Observing Part of the Electromagnetic Spectrum



1. Obtain a spectroscope, similar to the one shown in the illustration. Hold the end with the diffraction grating to your eye. Direct it toward a part of the sky away from the Sun. (CAUTION: never look directly at the Sun; doing so even briefly can damage your eyes permanently.) Look for a spectrum along the side of the spectroscope. Rotate the spectroscope until you see the colors going from left to right rather than up and down.
  - a) In your notebook, write down the order of the colors you observed.
  - b) Move the spectroscope to the right and left. Record your observations.
2. Look through the spectroscope at a fluorescent light.
  - a) In your notebook, write down the order of the colors you observed.
3. Look through the spectroscope at an incandescent bulb.
  - a) In your notebook, write down the order of the colors you observed.

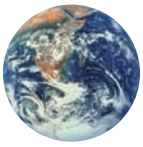


Do not look directly at a light with the unaided eye. Use the spectroscope as instructed.

4. Use your observations to answer the following questions:
  - a) How did the colors and the order of the colors differ between reflected sunlight, fluorescent light, and the incandescent light? Describe any differences that you noticed.
  - b) What if you could use your spectroscope to look at the light from other stars? What do you think it would look like?

### Part B: Scaling the Electromagnetic Spectrum

1. Tape four sheets of photocopy paper end to end to make one sheet 112 cm long. Turn the taped sheets over so that the tape is on the bottom.
2. Draw a vertical line 2 cm from the left edge of the paper. Draw two horizontal lines from that line, one about 8 cm from the top of the page, and one about 10 cm below the first line.
3. On the top line, plot the frequencies of the electromagnetic spectrum on a logarithmic scale. To do this, mark off 24 1-cm intervals starting at the left vertical line. Label the marks from 1 to 24 (each number represents increasing powers of 10, from  $10^1$  to  $10^{24}$ ).
4. Use the information from the table of frequency ranges ( $\log_{10}$ ) to divide your scale into the individual bands of electromagnetic radiation. For the visible band, use the entire band, not the individual colors.



Frequency Range Table			
EMR Bands	Frequency Range (hertz)	Log <sub>10</sub> Frequency Range (hertz)	10 <sup>14</sup> Conversions
Radio and Microwave	Near 0 to $3.0 \times 10^{12}$	0 to 12.47	.
Infrared	$3.0 \times 10^{12}$ to $4.6 \times 10^{14}$	12.47 to 14.66	.
Visible	$4.6 \times 10^{14}$ to $7.5 \times 10^{14}$	14.66 to 14.88	$4.6 \times 10^{14}$ to $7.5 \times 10^{14}$
Red	$4.6 \times 10^{14}$ to $5.1 \times 10^{14}$	14.66 to 14.71	$4.6 \times 10^{14}$ to $5.1 \times 10^{14}$
Orange	$5.1 \times 10^{14}$ to $5.6 \times 10^{14}$	14.71 to 14.75	$5.1 \times 10^{14}$ to $5.6 \times 10^{14}$
Yellow	$5.6 \times 10^{14}$ to $6.1 \times 10^{14}$	14.75 to 14.79	$5.6 \times 10^{14}$ to $6.1 \times 10^{14}$
Green	$6.1 \times 10^{14}$ to $6.5 \times 10^{14}$	14.79 to 14.81	$6.1 \times 10^{14}$ to $6.5 \times 10^{14}$
Blue	$6.5 \times 10^{14}$ to $7.0 \times 10^{14}$	14.81 to 14.85	$6.5 \times 10^{14}$ to $7.0 \times 10^{14}$
Violet	$7.0 \times 10^{14}$ to $7.5 \times 10^{14}$	14.85 to 14.88	$7.0 \times 10^{14}$ to $7.5 \times 10^{14}$
Ultraviolet	$7.5 \times 10^{14}$ to $6.0 \times 10^{16}$	14.88 to 16.78	.
X-ray	$6.0 \times 10^{16}$ to $1.0 \times 10^{20}$	16.78 to 20	.
Gamma Ray	$1.0 \times 10^{20}$ to...	20 to ...	.

5. To construct a linear scale, you will need to convert the range of frequencies that each band of radiation covers for the logarithmic scale. This will allow you to compare the width of the bands of radiation relative to each other. Convert the frequency numbers for all bands (except visible) to  $10^{14}$  and record them in the table.

Example:  $10^{17}$  is 1000 times greater than  $10^{14}$ , so  $2.5 \times 10^{17} = 2500 \times 10^{14}$ .

6. On the lower horizontal line, mark off ten 10-cm intervals from the vertical line. Starting with the first interval, label each mark with a whole number times  $10^{14}$ , from  $1 \times 10^{14}$  to  $10 \times 10^{14}$ . Label the bottom of your model "Frequency in hertz." Plot some of the  $10^{14}$  frequencies you calculated on the bottom line of your constructed model. Plot the individual colors of the visible spectrum and color them.

- a) Compare the logarithmic and linear scales. Describe the differences.
7. Look at the range of ultraviolet radiation.
- a) How high do the ultraviolet frequencies extend (in hertz)?
- b) Using the same linear scale that you constructed in Step 6 ( $10 \text{ cm} = 1 \times 10^{14} \text{ Hz}$ ), calculate the width (in centimeters) of the ultraviolet electromagnetic radiation band.
- c) Using this same scale what do you think you would need to measure the distance from the beginning of the ultraviolet band of the electromagnetic radiation to the end of the ultraviolet band of the electromagnetic radiation?
- d) Using your calculations above and the linear scale you created in Steps 5 and 6, how much wider is

the ultraviolet band than the entire visible band? How does this compare to the relative widths of these two bands on the log scale you created in Steps 1-4?

8. X-rays are the next band of radiation.
  - a) Using the same linear scale ( $10 \text{ cm} = 1 \times 10^{14} \text{ Hz}$ ) calculate the distance from the end of the ultraviolet band to the end of the x-ray band. Obtain a map from the Internet or use a local or state highway map to plot the distance.
  - b) Based on your results for the width of the x-ray band, what would be your estimate for the width of the gamma-ray band of radiation? What would you need to measure the distance?

### Part C: Using Electromagnetic Radiation in Astronomy

1. Astronomers use electromagnetic radiation to study objects and events within our solar system and beyond to distant galaxies. In this part of the activity, you will be asked to research a space science mission and find out how astronomers are using the electromagnetic spectrum in the mission and then report to the rest of the class. The *EarthComm* web site will direct you to links for missions that are either in development, currently operating, or operated in the past. A small sampling is provided in the table on the next page. Many missions contain multiple instruments (it is very expensive to send

instruments into space, so scientists combine several or more studies into one mission), so you should focus upon one instrument and aspect of the mission and get to know it well. The **Digging Deeper** reading section of this activity might help you begin your work.

Questions that you should try to answer in your research include:

- What is the purpose or key question of the mission?
  - How does the mission contribute to our understanding of the origin and evolution of the universe or the nature of planets within our solar system?
  - Who and/or how many scientists and countries are involved in the mission?
  - What instrument within the mission have you selected?
  - What wavelength range of electromagnetic radiation does the instrument work at?
  - What is the detector and how does it work?
  - What does the instrument look like?
  - How are the data processed and rendered? Images? Graphs?
  - Any other questions that you and your teacher agree upon.
2. When you have completed your research, provide a brief report to the class.





Descriptions of Selected Missions	
Mission/Instrument	Description
Hubble – NICMOS Instrument	Hubble’s Near Infrared Camera and Multi-Object Spectrometer (NICMOS) can see objects in deepest space—objects whose light takes billions of years to reach Earth. Many secrets about the birth of stars, solar systems, and galaxies are revealed in infrared light, which can penetrate the interstellar gas and dust that block visible light.
Cassini Huygens Mission to Saturn and Titan	The Ultraviolet Imaging Spectrograph (UVIS) is a set of detectors designed to measure ultraviolet light reflected or emitted from atmospheres, rings, and surfaces over wavelengths from 55.8 to 190 nm (nanometers) to determine their compositions, distribution, aerosol content, and temperatures.
SIRTF	The Space InfraRed Telescope Facility (SIRTF) is a space-borne, cryogenically cooled infrared observatory capable of studying objects ranging from our solar system to the distant reaches of the Universe. SIRTF is the final element in NASA’s Great Observatories Program, and an important scientific and technical cornerstone of the new Astronomical Search for Origins Program.
HETE-2 High Energy Transient Explorer	The High Energy Transient Explorer is a small scientific satellite designed to detect and localize gamma-ray bursts (GRB’s). The primary goals of the HETE mission are the multi-wavelength observation of gamma-ray bursts and the prompt distribution of precise GRB coordinates to the astronomical community for immediate follow-up observations. The HETE science payload consists of one gamma-ray and two x-ray detectors.
Chandra X-Ray Observatory	NASA’s Chandra X-ray Observatory, which was launched and deployed by Space Shuttle Columbia in July of 1999, is the most sophisticated x-ray observatory built to date. Chandra is designed to observe x-rays from high-energy regions of the universe, such as the remnants of exploded stars.

Reflecting on the Activity and the Challenge

The spectroscope helped you to see that visible light is made up of different color components. Visible light is only one of the components of radiation you receive from the Sun. In the second part of the activity, you explored models for describing the range of frequencies of energy within electromagnetic radiation.

Finally, you researched a space mission to learn how astronomers are using electromagnetic radiation to understand the evolution of the Earth system. Radiation from the Sun and other objects in the universe is something you will need to explain to your fellow citizens in your Chapter Challenge brochure.

## Digging Deeper

### ELECTROMAGNETIC RADIATION

#### The Nature of Electromagnetic Radiation

In 1666, Isaac Newton found that he could split light into a spectrum of colors. As he passed a beam of sunlight through a glass prism, a spectrum of colors appeared from red to violet. Newton deduced that visible light was in fact a mixture of different kinds of light. About 10 years later, Christiaan Huygens proposed the idea that light travels in the form of tiny waves. It's known that light with shorter wavelengths is bent (refracted) more than light with longer wavelengths when it passes through a boundary between two different substances. Violet light is refracted the most, because it has the shortest wavelength of the entire range of visible light. This work marked the beginning of **spectroscopy**—the science of studying the properties of light. As you will learn, many years of research in spectroscopy has answered many questions about matter, energy, time, and space.

In your study of the Sun you learned that the Sun radiates energy over a very wide range of wavelengths. Earth's atmosphere shields you from some of the most dangerous forms of electromagnetic radiation. You are familiar with the wavelengths of light that do get through and harm you—mostly in the form of sunburn-causing ultraviolet radiation. Now you can take what you learned and apply the principles of spectroscopy to other objects in the universe.

In the **Investigate** section, you used a **spectroscope** to study the Sun's light by separating it into its various colors. Each color has a characteristic wavelength. This range of colors, from red to violet, is called the **visible spectrum**. The visible spectrum is a small part of the entire spectrum of **electromagnetic radiation** given off by the Sun, other stars, and galaxies.

Electromagnetic radiation is in the form of electromagnetic waves that transfer energy as they travel through space. Electromagnetic waves (like ripples that expand after you toss a stone into a pond) travel at the speed of light (300,000 m/s). That's eight laps around the Earth in one second. Although it's not easy to appreciate from everyday life, it turns out that electromagnetic radiation has properties of both particles and waves. The colors of the visible spectrum are best described as waves, but the same energy that produces an electric current in a solar cell is best described as a particle.

#### Geo Words

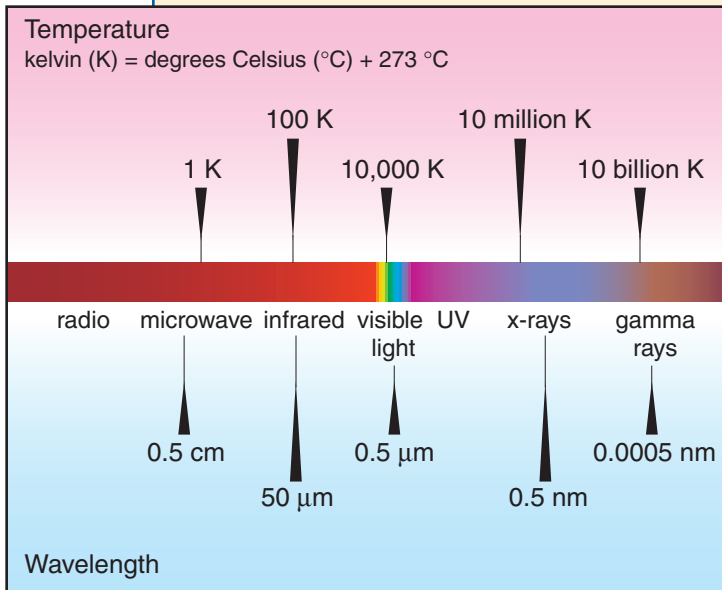
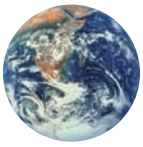
**spectroscopy:** the science that studies the way light interacts with matter.

**spectroscope:** an instrument consisting of, at a minimum, a slit and grating (or prism) which produces a spectrum for visual observation.

**visible spectrum:** part of the electromagnetic spectrum that is detectable by human eyes. The wavelengths range from 350 to 780 nm (a nanometer is a billionth of a meter).

**electromagnetic radiation:** the energy propagated through space by oscillating electric and magnetic fields. It travels at  $3 \times 10^8$  m/s in a vacuum and includes (in order of increasing energy) radio, infrared, visible light (optical), ultraviolet, x-rays, and gamma rays.





**Figure 1** The electromagnetic spectrum. Wavelengths decrease from left to right, and energy increases from left to right. The diagram shows that a relationship exists between the temperature of an object and the peak wavelength of electromagnetic radiation it emits.

Figure 1 summarizes the spectrum of energy that travels throughout the universe. Scientists divide the spectrum into regions by the wavelength of the waves. Long radio waves have wavelengths from several centimeters to thousands of kilometers, whereas gamma rays are shorter than the width of an atom.

Humans can see only wavelengths between 0.4 and 0.7 μm, which is where the visible spectrum falls. A micrometer (μm) is a millionth of a meter. This means that much of the electromagnetic radiation emitted by the Sun is invisible to human eyes. You are probably familiar, however,

with some of the kinds of radiation besides visible light. For example, **ultraviolet** radiation gives you sunburn. **Infrared** radiation you detect as heat. Doctors use x-rays to help diagnose broken bones or other physical problems. Law-enforcement officers use radar to measure the speed of a motor vehicle, and at home you may use microwaves to cook food.

### Astronomy and the Electromagnetic Spectrum

Humans have traveled to the Moon and sent probes deeper into our solar system, but how do they learn about distant objects in the universe? They use a variety of instruments to collect electromagnetic radiation from these distant objects. Each tool is designed for a specific part of the spectrum. Visible light reveals the temperature of stars. Visible light is what you see when you look at the stars through telescopes, binoculars, or your unaided eyes. All other forms of light are invisible to the human eye, but they can be detected.

**Radio telescopes** like the Very Large Array (VLA) and Very Large Baseline Array (VLBA) in New Mexico are sensitive to wavelengths in the radio range. Radio telescopes produce images of celestial bodies by recording the different amounts of radio emission coming from an area of the sky

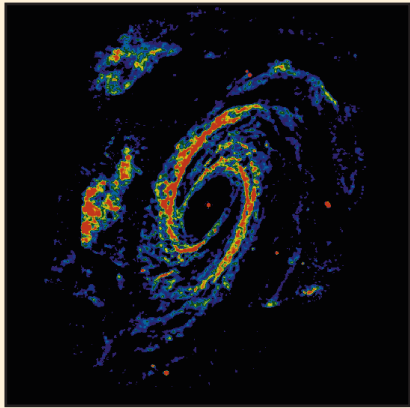
### Geo Words

**ultraviolet:** electromagnetic radiation at wavelengths shorter than the violet end of visible light; with wavelengths ranging from 5 to 400 nm.

**infrared:** electromagnetic radiation with wavelengths between about 0.7 to 1000 μm. Infrared waves are not visible to the human eye.

**radio telescope:** an instrument used to observe longer wavelengths of radiation (radio waves), with large dishes to collect and concentrate the radiation onto antennae.

observed. Astronomers process the information with computers to produce an image. The VLBA has 27 large dish antennas that work together as a single instrument. By using recorders and precise atomic clocks installed at each antenna, the signals from all antennas are combined after the observation is completed.



**Figure 2** The galaxy M81.

The orbiting Chandra **x-ray telescope** routinely detects the highly energetic radiation streaming from objects like supernova explosions, active galaxies, and black holes. The Hubble Space Telescope is outfitted with a special infrared instrument sensitive to radiation being produced by star-forming nebulae and cool stars. It also has detectors sensitive to ultraviolet light being emitted by hot young stars and supernova explosions.

A wide array of solar telescopes both on Earth and in space study every wavelength of radiation from our nearest star in minute detail. The tools of astronomy expand scientists' vision into realms that human eyes can never see, to help them understand the ongoing processes and evolution of the universe.

The galaxy M81 is a spiral galaxy about 11 million light-years from Earth and is about 50,000 light-years across. The spiral structure is clearly shown in *Figure 2*, which shows the relative intensity of emission from neutral atomic hydrogen gas. In this pseudocolor image, red indicates strong radio emission and blue weaker emission.

### Geo Words

**x-ray telescope:** an instrument used to detect stellar and interstellar x-ray emission. Because the Earth's atmosphere absorbs x-rays, x-ray telescopes are placed high above the Earth's surface.



**Figure 3** Astronauts working on the Hubble Space Telescope high above the Earth's atmosphere.







### Geo Words

**peak wavelength:** the wavelength of electromagnetic radiation with the most electromagnetic energy emitted by any object.

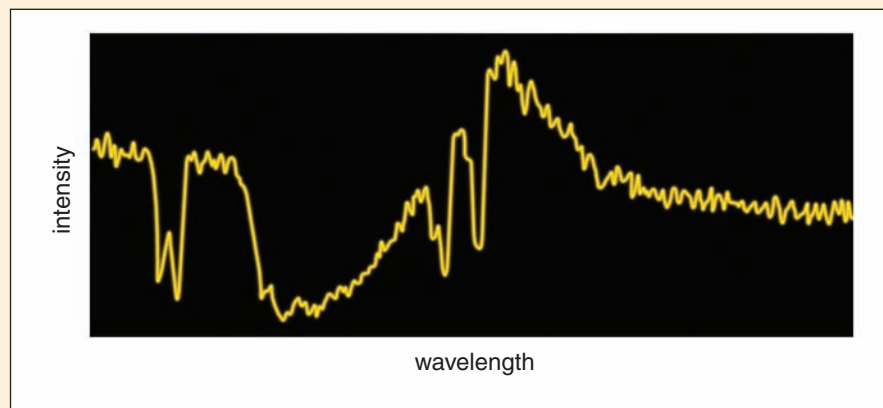
## Using Electromagnetic Radiation to Understand Celestial Objects

The wavelength of light with the most energy produced by any object, including the Sun, is called its **peak wavelength**. Objects that are hot and are radiating visible light usually look the color of their peak wavelength. People are not hot enough to emit visible light, but they do emit infrared radiation that can be detected with infrared cameras. The Sun has its peak wavelength in the yellow region of the visible spectrum. Hotter objects produce their peaks toward the blue direction. Very hot objects can have their peaks in the ultraviolet, x-ray, or even gamma-ray range of wavelength. A gas under high pressure radiates as well as a hot solid object. Star colors thus reflect temperature. Reddish stars are a “cool” 3000 to 4000 K (kelvins are celsius degrees above absolute zero, which is at minus 273°C). Bluish stars are hot (over 20,000 K).

One of the most important tools in astronomy is the spectrum—a chart of the entire range of wavelengths of light from an object. Astronomers often refer to this chart as the spectrum of the star. These spectra come in two forms: one resembles a bar code with bright and dark lines (see Figure 4), and the other is a graph with horizontal and vertical axes (see Figure 5). Think of these spectra as “fingerprints” that reveal many kinds of things about an object: its chemical composition, its temperature and pressure, and its motion toward or away from us.



**Figure 4** One of the forms of the spectrum of a star. The data encoded here tell astronomers that this star is bright in some elements and dim in others.



**Figure 5** The spectrum of a star can also be represented as a graph with horizontal and vertical axes.

Each chemical element in the universe has its own unique spectrum. If you know what the spectrum of hydrogen is, you can look for its fingerprint in a star. If you suspect that a star may have a lot of the elements helium or calcium, for example, you can compare the spectrum of the star with the known spectra of helium or calcium. If you see bright lines in the stellar spectrum that match the patterns of bright lines in the helium or calcium spectra, then you have identified those elements in the star. This kind of spectrum is known as an **emission spectrum**. If you look at the star and see dark lines where you would expect to see an element—especially hydrogen—it is likely that something between you and the star is absorbing the element. This kind of spectrum is known as an **absorption spectrum**.

The positions of lines in a spectrum reveal the motion of the star toward or away from Earth, as well as the speed of that motion. You have experienced the effect yourself, when a car, a truck, or a train passes by you with its horn blowing. The pitch of the sound increases as the object approaches you, and decreases as the object passes by and moves away from you. That is because when the object is coming toward you, its speed adds to the speed of the sound, making the wavelength of the sound seem higher to your ear. The reverse happens when the object is moving away from you. The same principle applies to the spectrum from a distant object in space, which might be moving either toward Earth or away from Earth.

### Geo Words

**emission spectrum:** a spectrum containing bright lines or a set of discrete wavelengths produced by an element. Each element has its own unique emission spectrum.

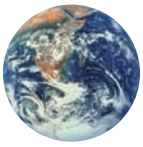
**absorption spectrum:** a continuous spectrum interrupted by absorption lines or a continuous spectrum having a number of discrete wavelengths missing or reduced in intensity.

### Check Your Understanding

1. What are the colors of the spectrum of visible sunlight, from longest wavelength to shortest? Are there breaks between these colors, or do they grade continuously from one to the next? Why?
2. Which wavelengths of light can be more harmful to you than others? Why?
3. What tools do astronomers use to detect different wavelengths of light?
4. How can the speed of a distant object in space be measured?

## Understanding and Applying What You Have Learned

1. Imagine that you are on a distant planet. Name two parts of the electromagnetic spectrum that you would use to investigate Earth. Explain the reasoning for your choices.
2. Refer to *Figure 1* to answer the questions below.
  - a) Describe the relationship between wavelength and energy in the electromagnetic spectrum.
  - b) Based upon this relationship, why do astronomers use x-ray telescopes to study supernova explosions and black holes?
3. The Sun looks yellow, can warm the surface of your skin, and can also give you a bad sunburn. Explain these three everyday phenomena in terms of the electromagnetic spectrum and peak wavelength.



## Preparing for the Chapter Challenge

Recall that your challenge is to educate people about the hazards from outer space and to explain some of the benefits from living in our solar system. Electromagnetic radiation has both beneficial and harmful effects on life on Earth. Use what you have learned in this activity to develop your brochure.

1. Make a list of some of the positive effects of electromagnetic radiation on your community. Explain each item on the list.
2. Make a list of some of the negative effects of electromagnetic radiation on your community. Explain each item on the list.
3. Make a list of celestial radiation sources and any effects they have on Earth systems. What are the chances of a stellar radiation source affecting Earth?

## Inquiring Further

1. Using radio waves to study distant objects

Radio waves from the Sun penetrate the Earth's atmosphere. Scientists detect these waves and study their strength and frequency to understand the processes inside the Sun that generate them. Do some research on how these waves are studied.

2. Detecting electromagnetic radiation

Investigate some of the instruments that astronomers use to detect electromagnetic radiation besides light. Where are you likely to find ultraviolet detectors? Describe radio telescope arrays.

3. Technologies and the electromagnetic spectrum

Research some of the technologies that depend on the use of electromagnetic radiation. These might include microwave ovens, x-ray machines, televisions, and radios. How do they work? How is electromagnetic radiation essential to their operation? What interferes with their operation?

